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MGGPOD: a Monte Carlo suite for modelling instrumental backgrounds in γ-ray astronomy and its application to Wind/TGRS and INTEGRAL/SPI

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Abstract

We have developed MGGPOD, a suite of Monte Carlo codes built around the widely used GEANT (Version 3.21) package, to simulate ab initio the physical processes relevant for the production of instrumental backgrounds. These include the build-up and delayed decay of radioactive isotopes as well as the prompt de-excitation of excited nuclei, both of which give rise to a plethora of instrumental γ-ray background lines in addition to continuum background. We demonstrate the capabilities of the MGGPOD suite by modelling high resolution γ-ray spectra recorded by the Transient Gamma-Ray Spectrometer (TGRS) on board Wind and the SPI spectrometer on board the recently launched INTEGRAL observatory.

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1. Introduction

Intense and complex instrumental backgrounds, against which the much smaller signals from celestial sources have to be discerned, are a notorious problem for low and intermediate energy γ-ray astronomy (∼50 keV–10 MeV). Therefore a detailed qualitative and quantitative understanding of instrumental line and continuum backgrounds is crucial for most stages of γ-ray astronomy missions, ranging from the design and development of new instrumentation through performance prediction to data reduction. A promising approach for obtaining quantitative estimates of instrumental backgrounds is Monte Carlo simulation (see e.g., Dean et al., 2003).

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We have developed a suite of Monte Carlo packages, named MGGPOD (Weidenspointner et al., 2003), that supports this type of simulation.

We demonstrate the capabilities of the MGGPOD suite by modelling high resolution γ-ray spectra recorded by the transient γ-ray spectrometer (TGRS) on board Wind during early 1995, and by the SPI spectrometer on board the recently launched INTEGRAL observatory in late 2002. We evaluate the successes and failures of the MGGPOD package in reproducing TGRS data. We also present preliminary modelling results for SPI, bearing in mind that it is a far more complex and massive instrument.

2. The MGGPOD Monte Carlo simulation suite

The MGGPOD Monte Carlo suite allows ab initio simulations of instrumental backgrounds – including the many γ-ray lines – arising from interactions of the various radiation fields within the instrument and spacecraft materials. It is possible to simulate both prompt instrumental backgrounds, such as energy losses of cosmic-ray particles and their secondaries, as well as delayed instrumental backgrounds, which are due to the decay of radioactive isotopes produced in nuclear interactions. Of course, MGGPOD can also be used to study the response of γ-ray instruments to astrophysical as well as calibration sources. The MGGPOD suite is therefore an ideal Monte Carlo tool for supporting most stages of γ-ray missions, ranging from design, development, and performance prediction over calibration and response generation to data reduction. A detailed description of the MGGPOD Monte Carlo suite can be found in Weidenspointner et al. (2003).

MGGPOD is a suite of five closely integrated Monte Carlo packages, namely MGEANT, GCALOR, PROMPT, ORIHET, and DECAY. The MGGPOD suite resulted from a combination of the NASA/GSFC MGEANT (Sturner et al., 2000) and the University of Southampton GGOD (Dean et al., 2003) Monte Carlo codes, which we supplemented with the newly developed PROMPT package. All these packages are based on the widely used GEANT Detector Description and Simulation Tool (Version 3.21) created and supported at CERN [1], which is designed to simulate the passage of elementary particles through an experimental set-up.

In a nutshell, the capabilities and functionalities of the five packages that constitute the MGGPOD suite are as follows:

- MGEANT is a multi-purpose simulation package that was created to increase the versatility of the GEANT simulation tool. A modular, "object oriented" approach was pursued, allowing for rapid proto-typing of detector systems and easy generation of most of the radiation fields relevant to γ-ray astronomy. Within the MGGPOD suite, MGEANT (i.e., GEANT) stores and transports all particles, and treats electromagnetic interactions from about 10 keV to a few TeV. MGEANT provides the option to use the GLECS/GLEPS package [2] to take into account the energy of bound electrons and photon polarization in Compton scatterings. The MGEANT simulation package and a user manual are available at a NASA/GSFC web site. [3]
- GCALOR (Zeitnitz and Gabriel, 1994) simulates hadronic interactions down to 1 MeV for nucleons and charged pions and down to thermal energies (10^{-5} eV) for neutrons. Equally important, this package [4] provides access to the energy deposits from all interactions as well as to isotope production anywhere in the simulated set-up.
- PROMPT simulates prompt photon emission associated with the de-excitation of excited nuclei produced by neutron capture, inelastic neutron scattering, and spallation.
- ORIHET, originally developed for the GGOD suite and improved for MGGPOD, calculates the build-up and decay of activity in any system for which the nuclide production rates are

[1] see http://www.info.cern.ch/asd/geant/

[2] see http://nis-www.lanl.gov/~mkippen/actsim/glecs/ by R.M. Kippen.

[3] see http://lheawww.gsfc.nasa.gov/docs/gamcosray/legr/mgeant/mgeant.html

[4] see http://wswww.physik.uni-mainz.de/zeitnitz/gcalor/gcalor.html

known. Hence ORIHET can be used to convert nuclide production rates, determined from simulations of cosmic-ray irradiation, to a decay rate, which is necessary input for simulating the radioactive decays giving rise to the delayed background.

- DECAY, again originally developed for GGOD and improved for our purposes, enables MGGPOD to simulate radioactive decays.

3. Modelling of Wind/TGRS

The TGRS instrument consists of a 215 cm^3 Ge crystal sensitive to energies in the 40–8000 keV band, which is kept at its operating temperature of 85 K by a passive radiative cooler (Owens et al., 1995). The resolution of TGRS at 500 keV was nominally about 3 keV full width at half maximum (FWHM).

The TGRS detector has no active shielding and is permanently exposed to $\sim 1.8\pi$ steradian of the southern Galactic hemisphere which is unobstructed by the cooler. Since its launch on November 1, 1994, Wind has spent virtually the whole mission in interplanetary space, well away from near-Earth radiation backgrounds such as geomagnetically trapped particles and Earth albedo radiations. The radiation environment experienced by TGRS therefore is dominated by two components: diffuse cosmic hard X and γ radiation, and Galactic cosmic rays.

The background spectra recorded by TGRS provide an ideal test for the MGGPOD package. The (relative) simplicity of the instrument design facilitated the development of an accurate computer model for Monte Carlo simulations (this also applies to the Wind spacecraft). The radiation environment of TGRS can also be modelled rather easily: the cosmic X and γ radiation was modelled according to Gruber et al. (1999); the Galactic cosmic-ray proton spectrum, corrected for solar modulation as of early 1995, was based on the models of Moskalenko et al. (2002). Finally, the fine energy resolution of the detector reveals the large number of instrumental lines in great detail, providing us with sensitive tests on the numerous interaction channels through which Galactic cosmic rays can deposit their energy in the instrument and spacecraft structures.

A comparison of the January–May 1995 TGRS spectrum with a MGGPOD simulation is shown in Fig. 1 (for ease of comparison with Fig. 2 the plot range is 20–8000 keV). The simulated background components are: prompt background due to cosmic-ray interactions and prompt de-excitations, delayed backgrounds from radioactive decays, and background due to cosmic X and γ rays. The sum of these simulated background components is depicted in grey, the data are shown in black. The MGGPOD simulation reproduces very well the

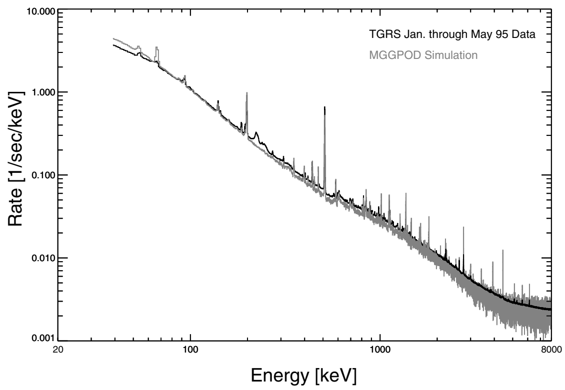

Fig. 1. A comparison of the January–May 1995 TGRS spectrum with a MGGPOD simulation. Details are given in the text. The broad features in the data between 210 and 260 keV are electronic artefacts.

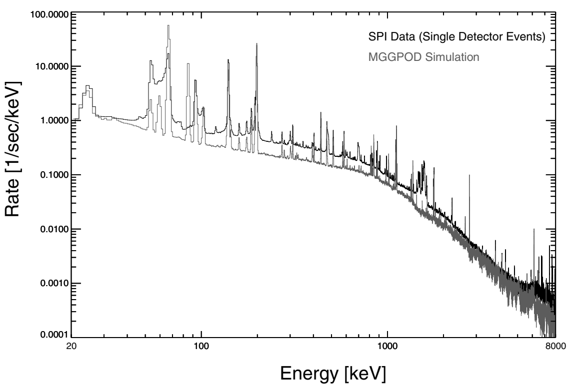

Fig. 2. A comparison of simulated SPI single detector events with actual flight data. Details are given in the text. The broad spikes in the data between 1.4 and 1.6 MeV are electronic noise.

overall shape and magnitude of the actual background with the difference between the two never exceeding 15%. The simulation is also very successful in modelling the more than 200 lines that are observed in the TGRS spectrum. Most (about 87%) of the lines are reproduced, with the ratio of simulated and actual line count rates clustering around a value of one with no trend in energy. The simulation produces a few spurious lines, and fails to reproduce a few lines that are in the data. A more detailed comparison and discussion is presented in Weidenspointner et al. (2003).

4. Modelling of INTEGRAL/SPI

The SPI spectrometer consists of an array of 19 actively cooled high resolution Ge detectors with a total volume of 3396 cm^3 (Vedrenne et al., 2003). The detectors cover an energy range of 20–8000 keV at an energy resolution of about 2–8 keV FHWM. SPI employs an active anti-coincidence shield made of bismuth germanate (BGO), which also acts as a collimator. INTEGRAL was launched into a highly elliptical orbit with a pergiee of 9000 km on October 17, 2002; hence its radiation environment is similar to that experienced by Wind and was modelled analogously.

A comparison of a MGGPOD simulation of SPI single detector events with actual flight data (an empty field observation in November 2002) is depicted in Fig. 2. It has to be emphasized that in this simulation the PROMPT package has *not* yet been included. The simulation comprises three background components: background due to cosmic X and γ rays, prompt background resulting from interactions of cosmic-ray protons, and delayed background due to radioactive decays. The sum of these simulated components is depicted in grey, the actual flight data are shown in black.

As can be seen in Fig. 2, the MGGPOD simulation reproduces well the overall shape and magnitude of the continuum background, and also reproduces well many lines from radioactive decays (prompt lines are not yet modelled). The simulation accounts for 71% of the observed total 20–8000 keV count rate. Below 4 MeV the simulation never falls short of the data by more than a factor of 2. At higher energies, where γ-rays from (thermal) neutron capture are important, but not yet included in the simulation, the difference can be larger. Modelling the SPI instrumental background by Monte Carlo simulation is an ongoing effort. A more detailed description and comparison will be presented in a forthcoming publication.

5. Summary

The MGGPOD Monte Carlo suite is an ideal tool for supporting most stages of γ-ray missions, ranging from design, development, and performance prediction over calibration and response generation to data reduction. We provide an overview of the functionalities of the five packages comprising MGGPOD, and demonstrate its capabilities for modelling instrumental backgrounds by applying it to Wind/TGRS and INTEGRAL/SPI. MGGPOD is very successful in modelling both the continuum and line backgrounds of the rather simple and light TGRS detector, and it is successful at modelling the much more complex and massive SPI spectrometer. Remaining deficiencies, some of which we suspect result from insufficient treatment of the production, thermalization, and capture of secondary neutrons, are being investigated. We expect secondary neutrons to be a source of instrumental background which becomes increasingly important with increasing mass of instrument and spacecraft. Hence secondary neutrons and the resulting backgrounds due to neutron activation and capture (γ-rays from the latter process are not yet included in Fig. 2) should be of particular relevance for SPI.

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